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Eric Rice (Orbitec) "ORBITEC Advanced Cryogenic Solid Hybrid Rocket Engine and Propellant Developments: A 1998 Status Report"

HEDM **(Statement A)**

ORBITEC Advanced Cryogenic Solid Hybrid Rocket Engine and Propellant Developments: A 1998 Status Report

by

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1998 HEDM CONFERENCE
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USAF Phillips Laboratory, Edwards Air Force Base, CA
COTR Dr. Patrick G. Carrick, OLAC-PL

"Cryogenic Hybrid Rocket Engine for Testing High-Energy Propellants"
USAF Contracts F04611-96-C-0034 & F04611-97-C-0020
USAF Phillips Laboratory, Edwards Air Force Base, CA
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"Metallized Cryogen for Advanced Hybrid Engines"
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Introduction

- Overview
- Mark II Engine and Supporting Hardware
- SOX/GH_2 Hybrid Firings
- SC_2H_2/GOX Firings
- SCH_4/SOX Solid Propellant Firings
- SCO/GOX Firing
- Regression Rate Summary
- Current R&D Activity
- Summary of Latest Findings

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Overview

- **ORBITEC First Proposed Cryogenic Solid Hybrid Rocket Engine Applications to USAF/PL under SBIR Program in 1991-1992 to Support the HEDM Program**

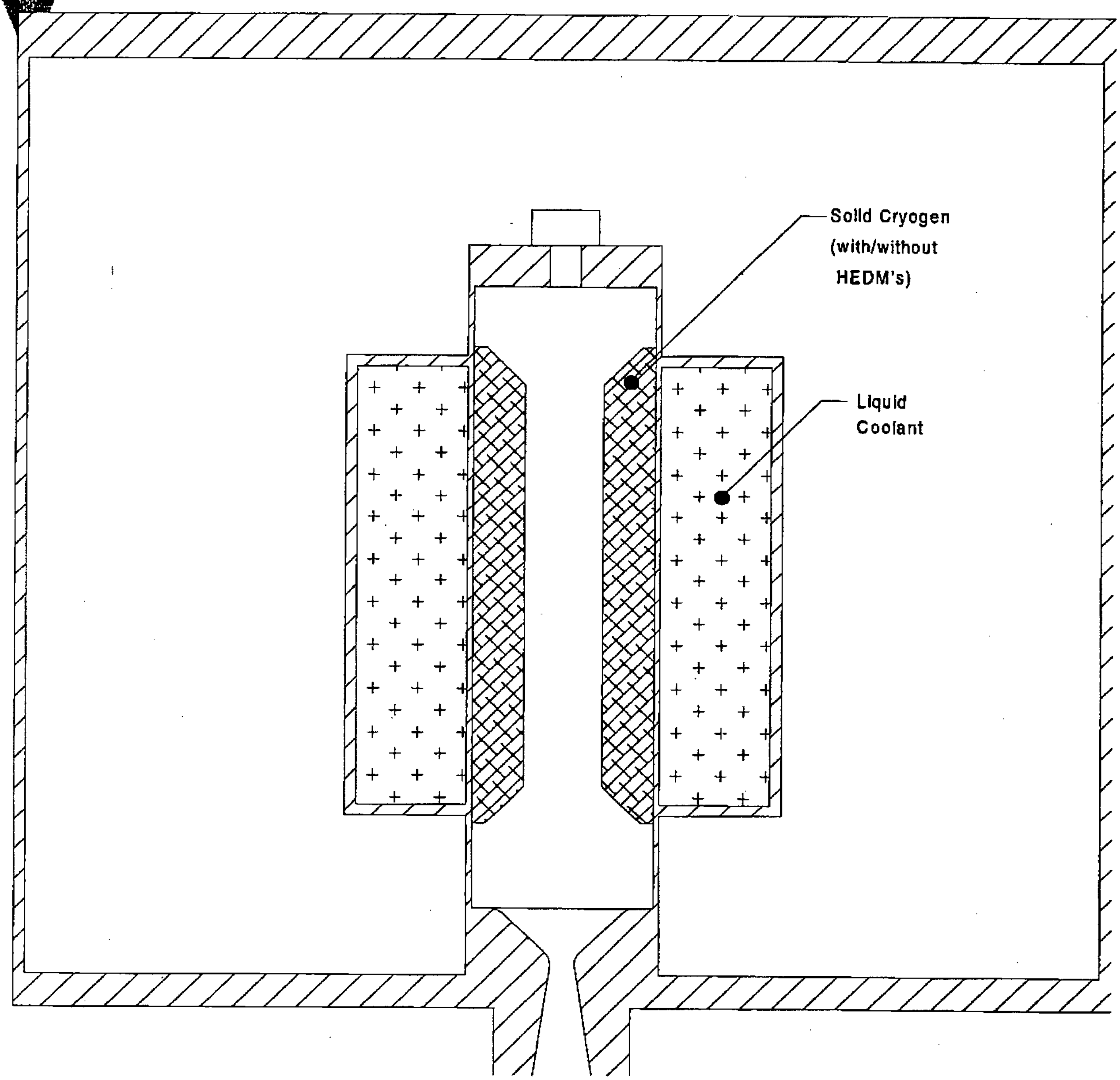
- **ORBITEC Has Had Eight Contracts in this Technology Area Under USAF/RL and NASA SBIR Funding**

- **Currently Designing, Developing, Testing, and Demonstrating Hybrid Engines for Combustion Testing of Solid Cryogens, Including Oxygen, Hydrogen, Methane, Acetylene, Carbon Monoxide**

- **ORBITEC Successfully Fired:**
  - **First SOX/GH_2 Hybrid Rocket on August 21, 1995**
  - **First SCH_4/GOX Hybrid Rocket on October 10, 1995**
  - **First SH_2/GOX Hybrid Rocket on October 25, 1996**
  - **First SCH_4-AL/GOX Hybrid Rocket on November 9, 1996**
  - **First SC_2H_2/GOX Hybrid Rocket on September 25, 1997**
  - **First SCH_4/SOX Rocket Motor on October 7, 1997**
  - **First SCO/GOX Hybrid Rocket on January 29, 1998**

- **Plan For the First SOX/LH_2 Engine Firing in Larger Mark III Engine Late 1998**

Engine Concept Design Sketch



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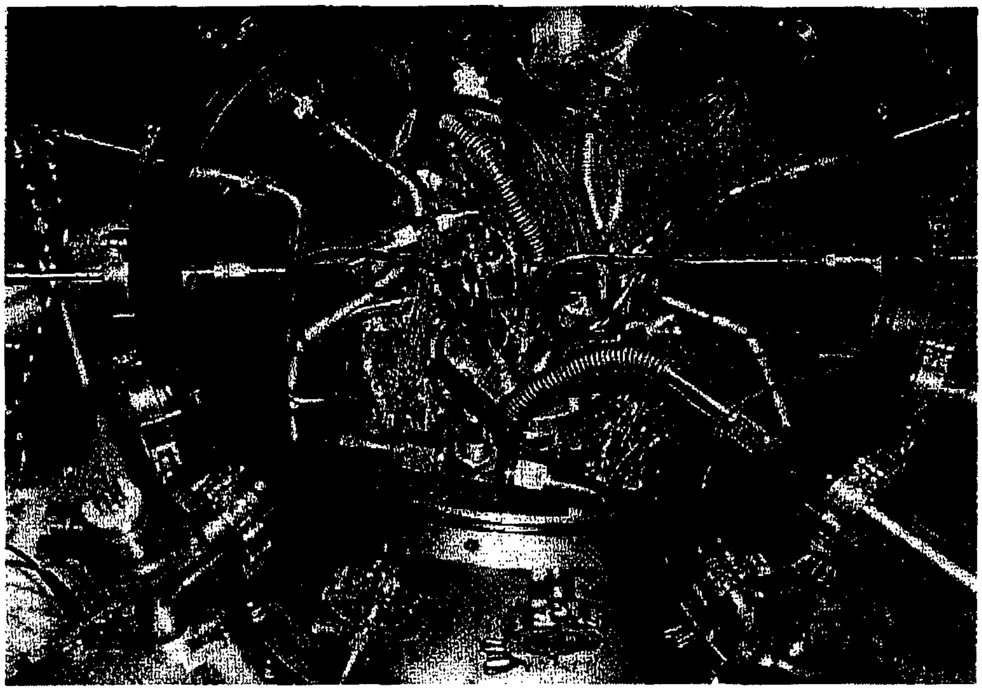
Mark II Cryogenic Hybrid Engine



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Summary of Latest SOX/GH$_2$ Firings in Mark II Engine

Firing #	Date	O_2 Mass (g)	H2 Mass Flow (g/s) Head End	Aft End	Peak Pres. (psia)	Dur-ation (sec)	Avg. O/F	C* (m/s)	C* eff.	Inj. Diam. (in.)	Notes
G60-P001	14 May 97	50	1.4	0.2	210	2.0	17	1210	71%	0.136	Reversed flows (head/aft)
G60-P002	15 May 97	50	0.2	1.4	150	2.9	12	1350	72%	0.136	
G60-P003	23 May 97	50	0.2	1.4	160	3.1	11	1640	85%	0.136	Installed inter-chamber restriction
G60-P004	06 Jun 97	50	0.09	1.5	130	3.7	8.5	1610	77%	0.136	
G60-P005	09 Jun 97	50	0.04	1.6	130	4.0	7.7	1710	80%	0.136	
G60-P006	13 Jun 97	50	0.09	1.5	160	4.0	7.9	1670	78%	48 h.	48 hole tube injector
G60-P007	20 Jun 97	50	0.09	1.5	140	3.8	8.2	1590	76%	Por.	Porous tube injector
G60-P008	26 Jun 97	150	0.09	2.3	210	9.7	6.4	1730	77%	Long	3" long extended injector
G60-P009	18 Jul 97	50	0.01	2.4	95	8.8	2.4	2090	82%	0.136	
G60-P010	22 Jul 97	150	0.01	2.4	160	18	3.5	2030	81%	0.136	
G60-P011	23 Jul 97	50	0.02	2.4	60	9.6	2.2	1540	61%	0.136	
G60-P012	04 Feb 98	150	3.0	0.0	110	4.7	11	1600	81%	0.136	Removed aft injector
G60-P013	05 Feb 98	150	6.0	0.0	170	4.7	5.3	2070	87%	0.136	
G60-P014	09 Feb 98	150	–	–	--	–	–	--	–	0.136	Aluminized grain
G60-P015	17 Apr 98	150	3.0	0	120	2.8	19	920	55%	0.129	Warm grain
G60-P016	22 Apr 98	150	0.09	3.1	260	14	3.3	1980	77%	0.020	Mixing plate, aft injector
G60-P017	24 Apr 98	150	0	1.75	220	16	7.0	1710	77%	0.191	Pilot oxygen flow (3 g/s)
G60-P018	29 Apr 98	150	7.5	0.0	160	3.9	4.3	1930	79%	0.191	
G60-P019	05 May 98	150	6.0	0.0	90	3.0	?	?	?	0.191	Freez. gas change, ceramic shield
G60-P020	06 May 98	150	6.0	0.0	130	6.5	3.9	2130	86%	0.191	Copper shield
G60-P021	07 May 98	100	6.0 +/-	0.0	130	4.9	3.5	2090	83%	0.191	Step hydrogen flow profile

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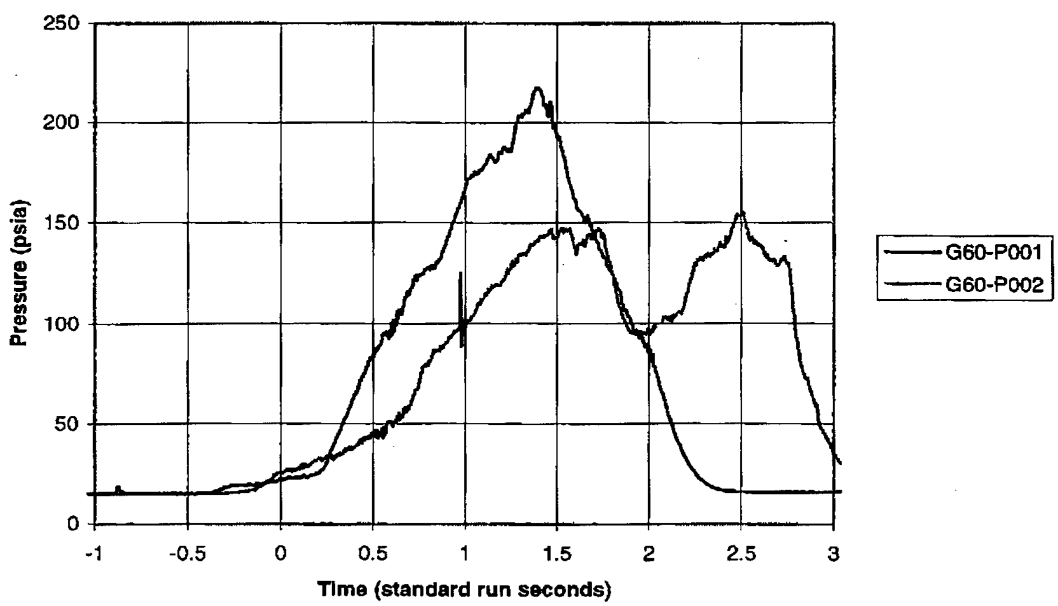
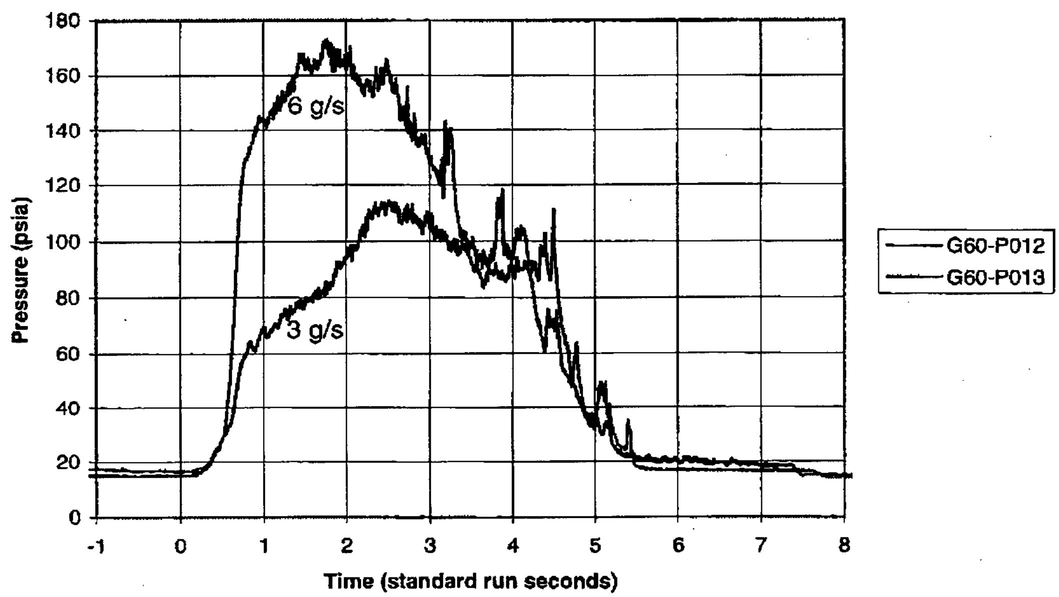
SOX/GH2 Firings in Mark II Engine

Effect of Pilot Flow vs. Aft Ignition



SOX/GH$_2$ Firings in Mark II Engine

Effect of Hydrogen Flow Rate



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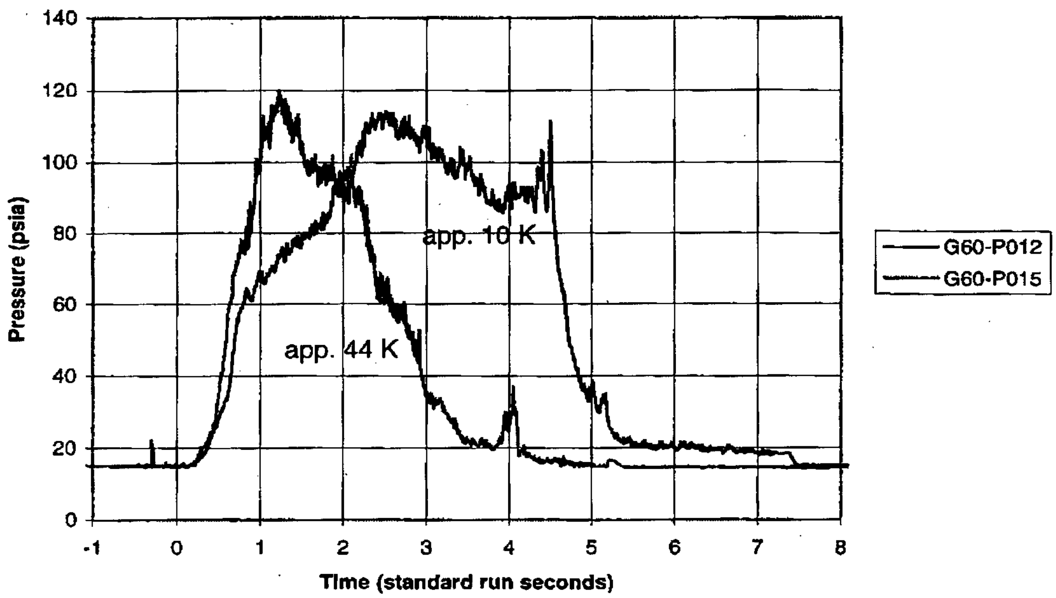
SOX/GH_2 Firings in Mark II Engine

Effect of Grain Temperature



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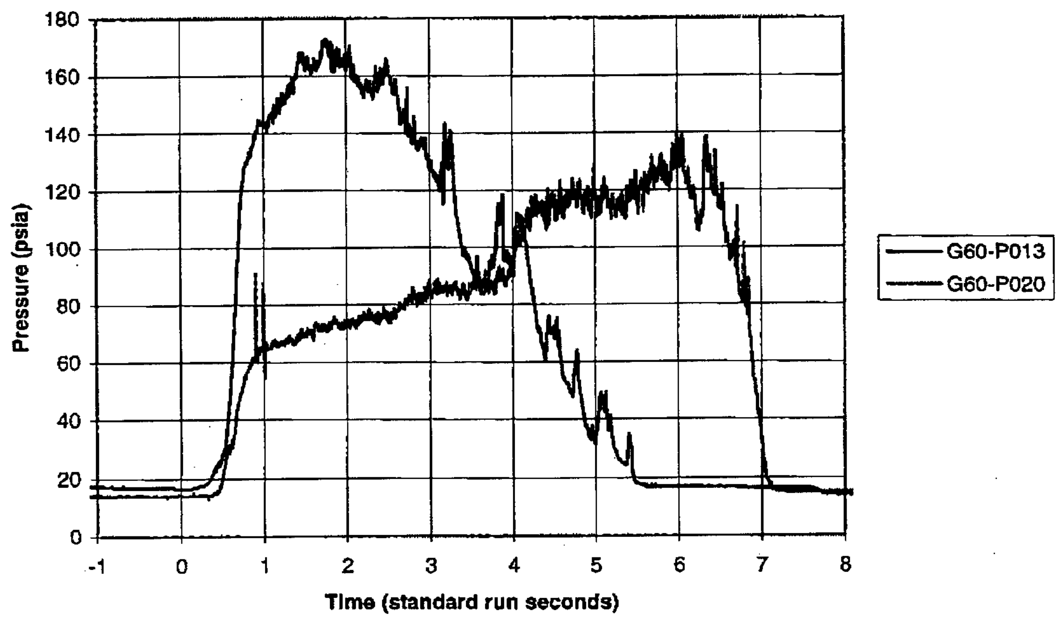
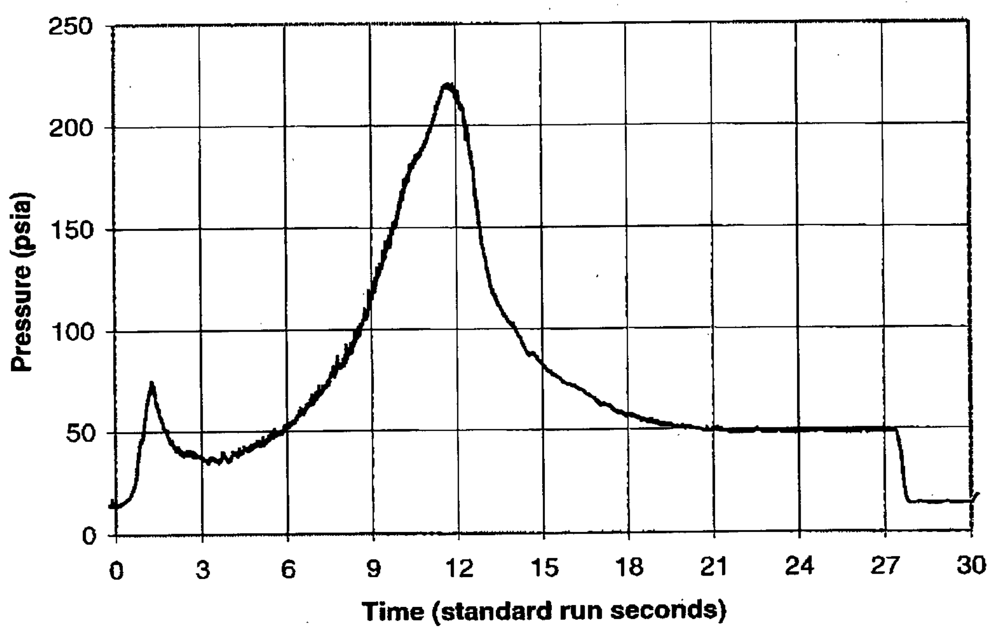
SOX/GH2 Firings in Mark II Engine

Effect of Injection Velocity, Grain Quality



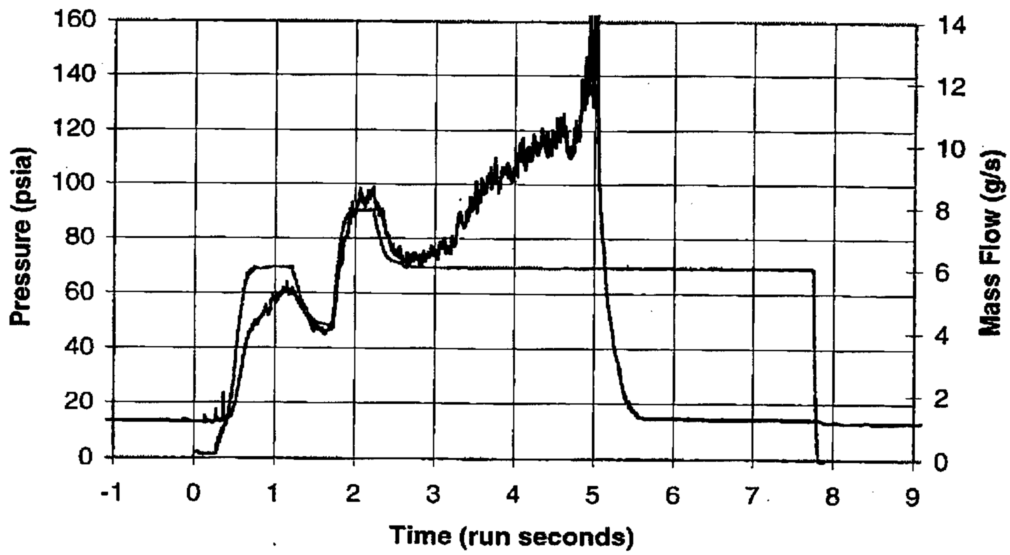
SOX/GH2 Firings in Mark II Engine

Oxygen Pilot Flow Test



SOX/GH2 Firings in Mark II Engine

Response to Changes in Hydrogen Flow



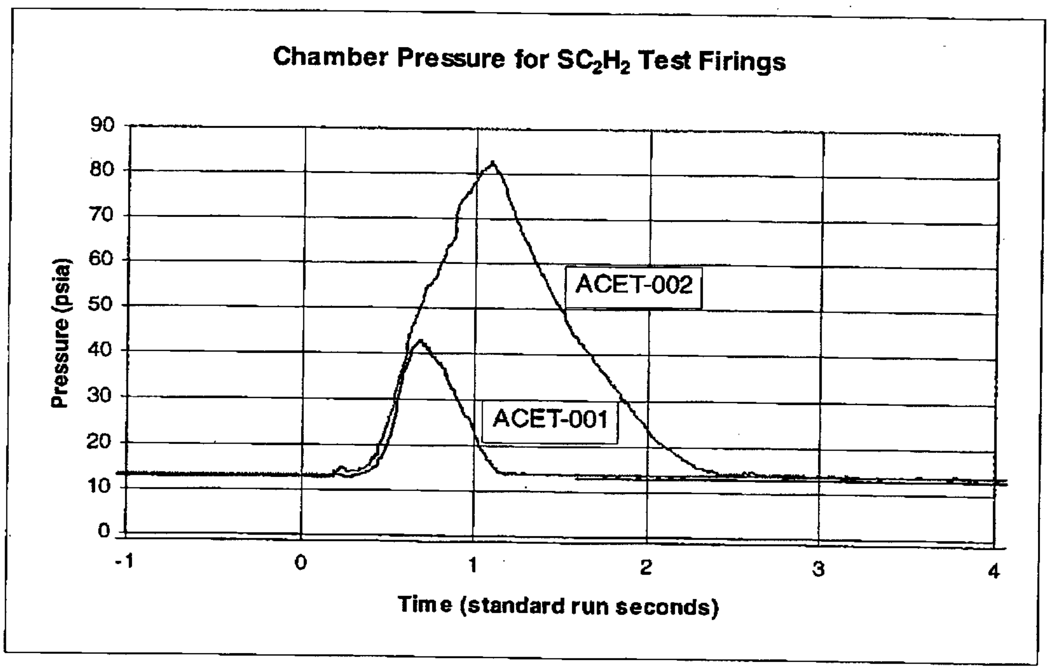
SC_2H_2/GOX Successful Firings

SC_2H_2 Test Firing #1

Date: 25 Sept. 1997
Grain Mass: 1.0 g
GOX Flow: 6.6 g/s
GOX Ramp: 0.5 s
Ignitor O/F: 2.5
Ignitor flow: 0.18 g/s

SC_2H_2 Test Firing #2

Date: 26 Sept. 1997
Grain Mass: 10 g
GOX Flow: 6.6 g/s
GOX Ramp: 0.5 s
Ignitor O/F: 2.5
Ignitor flow: 0.18 g/s



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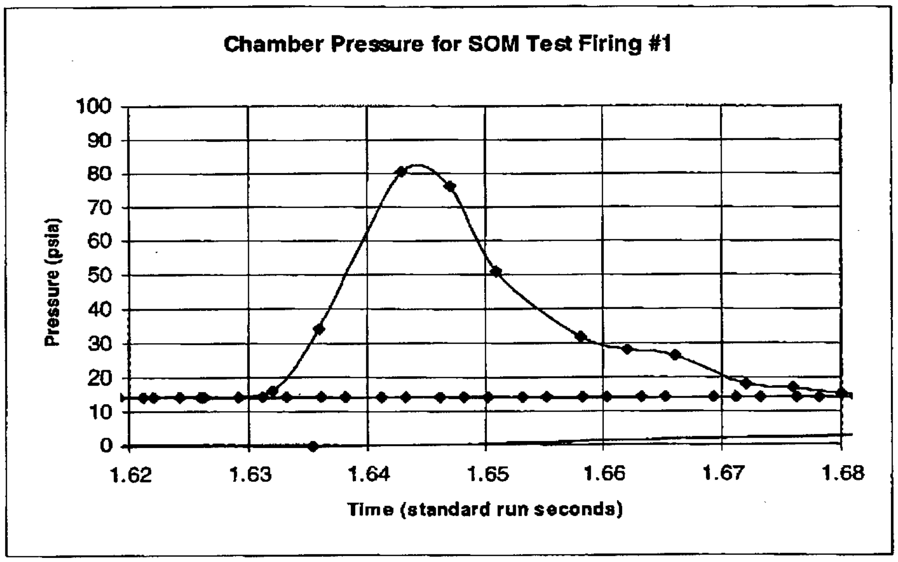
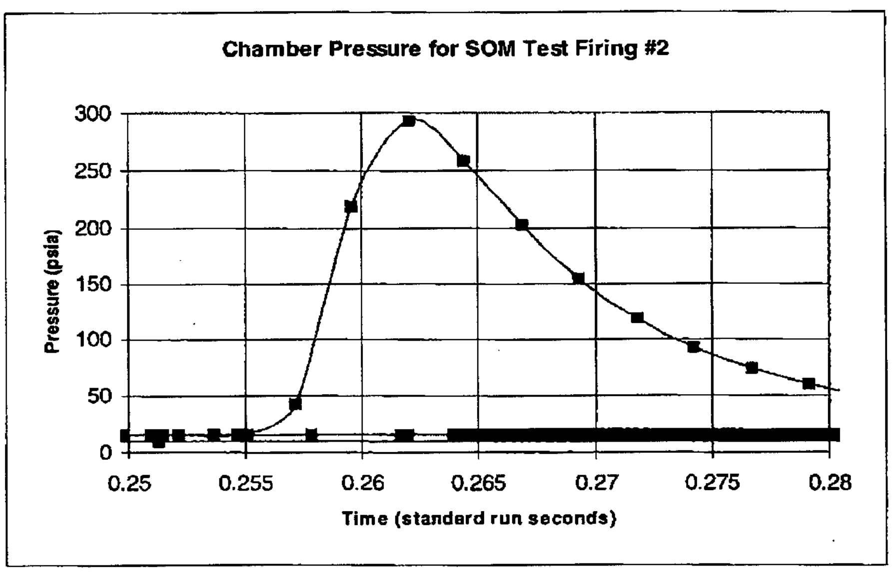
SCH_4/SOX Solid Propellant

SOM Test Firing #1
Date: 7 October 1997
Grain Mass: 0.6 g
SOM O/F: 2.4
Ignitor O/F: 2.5
Ignitor flow: 0.18 g/s
Tubing run to transducer: app. 18"

SOM Test Firing #2
Date: 8 October 1997
Grain Mass: 1.0 g
SOM O/F: 2.4
Ignitor O/F: 5
Ignitor flow: 0.26 g/s
Tubing run to transducer: app. 4"





SCO/GOX Firing

January 29, 1998

Grain Mass: 100 g

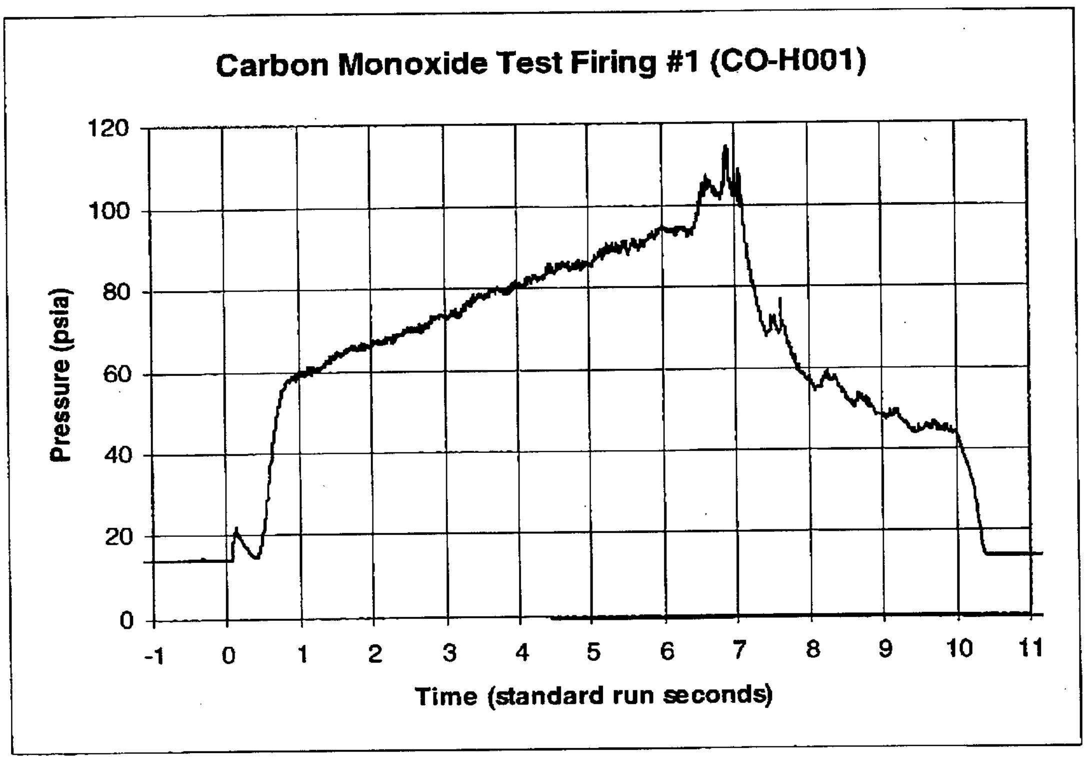
GOX Flow: 6 g/s

Average Pressure: 71 psia

Average O/F: 0.57

Experimental C*: 114 s

C* Efficiency: 83%



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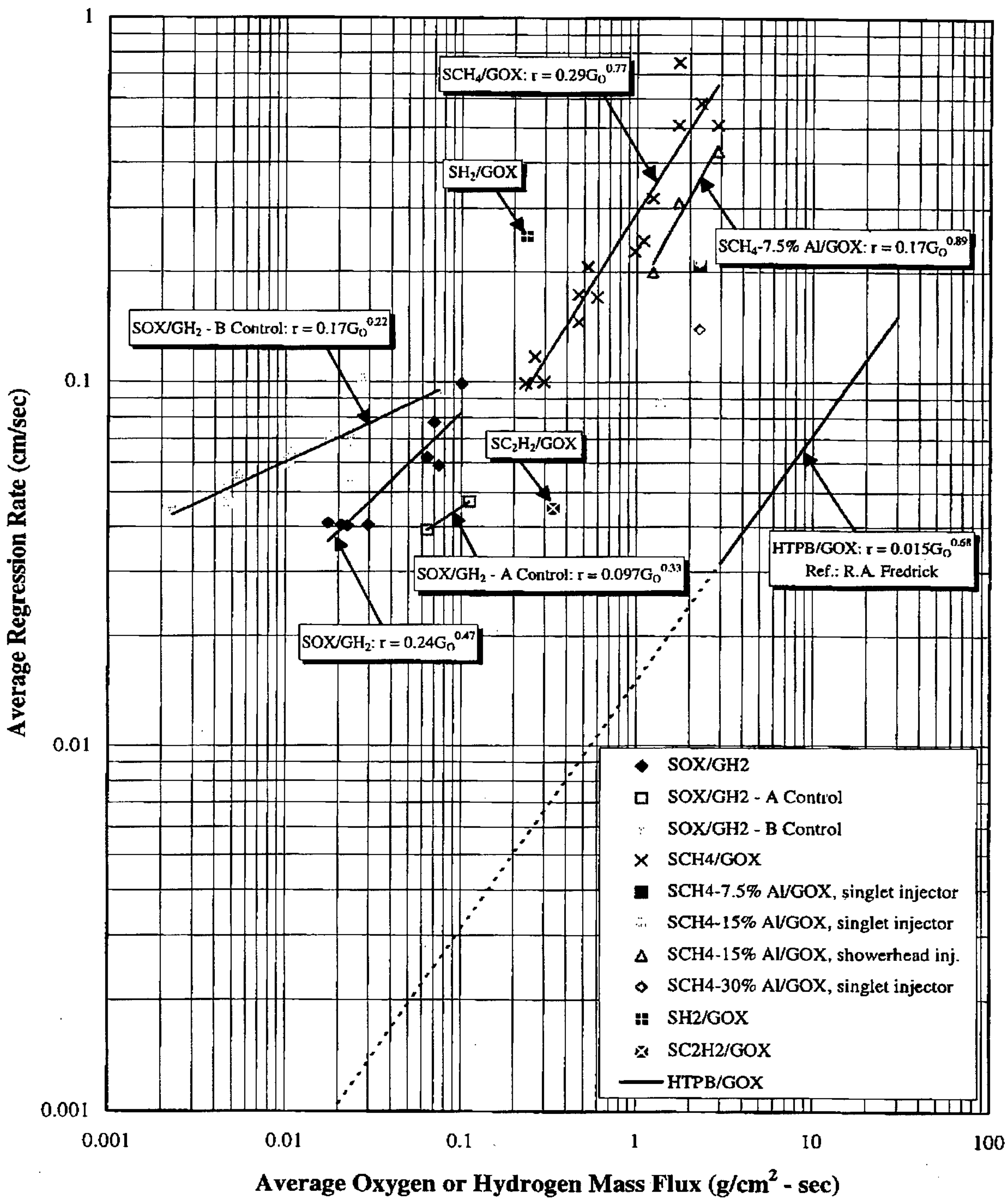
Regression Rate Summary



Current R&D Activity

Sponsored by USAF/PL Under Contract F04611-97-C-0020

- **Currently in Design of Systems and Approaches to Control Regression Rates to Optimize Engine Performance (O/F ratio and C*)**

- **Mark II Engine Firings are On-going with SOX/GH_2 to Prove Best Combustion Control Approaches**

- **Goal Is to Design, Develop, Test and Demonstrate a Flight-Weight-Type System (Mark III) that Uses LH_2 for the SOX Freeze Coolant and Also As the Fuel in the Engine**

- **The use of Ozone is Also Being Integrated Into the Design Approach**

- **We are working with Boeing-Rocketdyne and Boeing-Seattle to Help Assess Our Current and Future Systems Designs and Applications**

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Summary of Latest Findings

- **O/F ratios have approached optimum values with higher hydrogen flow rates, with and without O/F ratio control measures**
- **Axisymmetric freezing of SOX and shorter ignitor burn times seemed to minimize the characteristic grain breakup at the end of the burn**
- **Injection velocity has a significant effect on regression rate**
- **GH_2 pilot flow control demontrated total burning control of the engine with controlled aft injection**
- **LHe-cooled grains (to 10 K), when burned, exhibit lower regression rates and higher performance than warmer GHe-cooled grains (44 K)**
- **SC_2H_2 may be frozen readily from the gas phase using liquid nitrogen**
- **SCO/GOX burned very well (and hot!) with a stable pressure trace and at a stoichiometric O/F ratio on the 1st Use of mixing plate between the forward/aft chamber**

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Summary of Latest Findings (Cont.)

- **SCO/GOX is an excellent candidate for an ISRU Mars sample return mission**

- **GOX pilot flow extend the burn time and smoothed out the pressure curve significantly**

- **Initial evidence indicates that C_2H_2 is stable in the solid phase: stable burning was observed at pressures above 80 psia**

- **Fuel-rich combustion with SC_2H_2 produced significant sooting**

- **Both SOM grains burned too fast for the pressure transducers to track the chamber pressure; additives may slow combustion in future tests**

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